Activity 4

Protecting the Herd

At a Glance

Focus: Students use in-class and CD-ROM-based simulations of the spread of an infectious disease through a population to discover the phenomenon of herd immunity.

Major Concepts: The re-emergence of some diseases can be explained by the failure to immunize enough individuals, which results in a greater proportion of susceptible individuals in a population and an increased reservoir of the infectious agent. Increases in the number of individuals with compromised immune systems (due to the stress of famine, war, crowding, or disease) also explain increases in the incidence of emerging and re-emerging infectious diseases.

Objectives: After completing this activity, students will

- be able to explain how immunizing a significant proportion of a population against a disease prevents epidemics of that disease (herd immunity),
- be able to list factors that affect the proportion of a population that must be immunized to prevent epidemics, and
- understand how large-scale vaccination programs help control infectious diseases.

Prerequisite Knowledge: Students should be familiar with how immunization protects individuals from infectious diseases.

Basic Science-Public Health Connection: This activity introduces students to modeling as a scientific exercise. Students learn how models based on observations of disease transmission can be used to predict the likelihood of epidemics and to help public health officers recommend policies to protect the public from infectious diseases.

Introduction

Global vaccination strategies are a cost-effective means of controlling many infectious diseases. Because immunized people do not develop diseases that must be treated with antimicrobial drugs, opportunities for pathogens to evolve and disseminate drug resistance genes are reduced. Thus, mass immunization reduces the need to develop newer and more expensive drugs.

As long as a disease remains endemic in some parts of the world, however, vaccination programs must be maintained everywhere, because an infected individual can travel anywhere in the world within 24 hours. Once global vaccination programs eliminate the infectious agent (as in the case of the smallpox virus), vaccination is no longer necessary and the expense of those programs is also eliminated. It is estimated that the United States has saved $17 billion so far as a result of the eradication of smallpox (which cost, according to the World Health Organization, $313 million across a 10-year period).

Lapses in vaccination programs explain the re-emergence of some infectious diseases. For example, the diphtheria outbreak in Russia in the early 1990s may have been due to lapses in vaccination programs associated with the breakup of the Soviet Union. Inadequate vaccines and failure to obtain required "booster shots" also explain some disease re-emergence. The dramatic increase in measles cases in the United States during 1989–1991 was likely caused by failure to give a second dose of the vaccine to school-age children. The American Academy of Pediatrics now recommends that all children receive a second dose of the measles vaccine at either age 4–6 or 11–12.

This activity and Activity 3, *Superbugs: An Evolving Concern*, both provide explanations for the re-emergence of some infectious diseases. Activity 3 explained that some re-emerging diseases are due to the evolution of antibiotic resistance among pathogens. Activity 4, *Protecting the Herd*, introduces students to the idea that the re-emergence of other infectious diseases can be explained by a failure to immunize a sufficient proportion of the population. On the first day of the activity, students learn that epidemics can be prevented by immunizing part of the population, leading to herd immunity. The concept of herd immunity is elaborated in the optional, second day of the activity. Here, students learn that the threshold level of immunity required to establish herd immunity (and thus prevent epidemics) varies depending on the transmissibility of the disease, the length of the infectious period, the population density, and other factors.

Materials and Preparation

You will need to prepare the following materials before conducting this activity:

- Master 4.1, *Measles Outbreak at Western High* (make 1 per student)
- Master 4.2, *A Little Sleuthing* (make 1 per student)
- Master 4.3, *Following an Epidemic* (make 2 per student and 2 transparencies)
- red, pink, and black cards (make 1 of each per student)
- folded pieces of paper labeled "immune" and "susceptible" (make enough of each for half the students)

If you do Day 2 of the activity, you will also need the following materials:

- Master 4.4, *Disease Transmission Simulation Record* (make 1 per student)
- Master 4.5, *Characteristics of Smallpox, Polio, and Measles* (make 1 transparency)
- Master 4.6, *Cases of Smallpox in Niger and Bangladesh* (make 1 transparency)
- blank transparencies
- *Emerging and Re-emerging Infectious Diseases* CD-ROM

Follow the instructions on page 31 to load the CD-ROMs on the computers students will use.

Note to teachers: If you do not have enough computers equipped with CD-ROM drives, you will not be able to conduct the optional Day 2 of this activity.

Procedure

DAY 1

1. **Introduce the activity by distributing one copy of Master 4.1, *Measles Outbreak at Western High*, to each student and asking the students to read it.**

   The scenario described on *Measles Outbreak* is fictitious, but is based on an outbreak of measles that occurred in Washington State in 1996.

   An alternate way to introduce the activity is to assign students to make a list of the childhood diseases that they, their parents (or someone from their parents' generation), and their grandparents' (or someone from their grandparents' generation) had. Explain that "childhood diseases" means diseases that people usually have just once and do not get again (for example, chicken pox). Explain that you do *not* mean diseases like the flu, strep throat, and colds. On the day you wish to begin the activity, ask students to name some of these diseases, then ask them to count the *number of different diseases* each generation in their family had. Total these numbers across all of the students in the class and ask students to suggest why (in general) their parents and grandparents had more diseases than they did. Students likely will suggest (correctly) that vaccination against many diseases is now available.

2. **After students have read *Measles Outbreak*, ask them to speculate about what might have happened to cause a sudden outbreak of a disease such as measles that normally, today, is relatively rare in the United States.**

   Students likely will know that most children in the United States today are vaccinated against measles. They may speculate that the students at Western High were not vaccinated, or that the vaccine didn't work in their cases, or even that the pathogen causing this form of measles was somehow able to evade the immune defenses that had been triggered by the vaccinations these children received.

3. **Distribute one copy of Master 4.2, *A Little Sleuthing*, to each student and ask the students to read the story and think about the question that ends it.**

4. **Point out that despite the success of the measles vaccine, there continue to be small outbreaks of measles in the United States. Explain that the key to understanding why this is true and to answering the question that ends the story about Western High lies in understanding how disease spreads in a population.**

5. **Explain to students that to help them understand how disease spreads in a population, they will participate in a simulation of the spread of a fictitious disease you will call the "two-day disease." Distribute two copies of Master 4.3, *Following an Epidemic*, to each student and display a transparency of this master. Then direct students to perform two simulations of the spread of two-day disease, according to the instructions provided on page 77, immediately following the activity.**

This is an opportunity to point out that research in microbiology and related disciplines in the last 50 years has led to the development of many vaccines in addition to the measles vaccine. Children of the 1990s who receive recommended vaccinations are protected from many infectious diseases that plagued children in the past, including diphtheria, whooping cough, measles, hepatitis B, and chicken pox.

An "epidemic" is typically defined as "more cases of a disease than is expected for that disease." Although this is not a very specific definition, it does make it clear that whether scientists call an outbreak of a disease an epidemic depends on the specific disease involved. Though there is no distinct line between an "outbreak" and an "epidemic," epidemics are generally considered to be larger in scale and longer lasting than outbreaks. Today, five cases of measles within a population could be considered an epidemic because *no* cases are expected.

For this simulation, assume that an epidemic is in progress if 25 percent or more of the population is sick at one time.

Observations that students might make about the table and graph that result from the first simulation include:

- an epidemic occurred because a large portion of the class was sick at the same time;
- at the beginning of the epidemic, only a few people were sick in the same day; in the middle of the epidemic, a lot of people were sick at the same time; and at the end, only a few people were sick;
- by the end of the simulation, everyone was immune; and
- once it started, the disease spread rapidly.

Observations that students might make about the table and graph that result from the second simulation include:

- only a few people were sick on any one day;
- no epidemic occurred;
- at the end of the simulation, some people were still susceptible; and
- some people in the population never got sick.

Tip from the field test. Do a practice run of several days of the simulation before you do the runs in which you collect data. This will allow you to address any confusion students have about the simulation and will make subsequent runs go much faster. If you have time, you may want to repeat the simulation, in particular the second simulation in which half of the class is immune. In order for students to observe herd immunity, some susceptible students in the population should not get sick. Depending on the arrangement of immune and susceptible students in the class (which is random), this may not happen the first time you run this simulation.

6. **Debrief the activity by asking, "Why did an epidemic occur in the first population, but not in the second?" and "Why didn't all of the susceptible people in the second population get sick?" Introduce the term "herd immunity" and describe it as a phenomenon that occurs when most of the people in a population are immune to an infectious disease. Susceptible people in the population are protected from that disease because the infectious agent cannot be effectively transmitted.**

Allow students to discuss their responses to the two questions before you introduce the term "herd immunity." Students will likely make comments such as "Everyone sitting near John was immune, so the disease just died out." At that point, you can respond by saying, "Yes, what you have just explained is what epidemiologists call 'herd immunity'." Then you can provide a more complete definition.

7. **Ask students to explain, based on their experience in the disease transmission simulation, what would happen if measles vaccinations dropped to a low level in a population.**

   Students should be able to explain that there would be many susceptible people in the population, so the disease would be transmitted from one to another without dying out. A measles outbreak or epidemic would occur. If students do not mention "re-emergence," emphasize this point by saying "Yes, measles would re-emerge in the population."

This step takes students to the major concept of the activity: The re-emergence of some diseases can be explained by immunity levels that are below the level required for herd immunity.

8. **Remind students about the measles outbreak story. Ask them to write a final paragraph to the story in which they use the term herd immunity to answer the following questions:**

   - **Why didn't the unvaccinated or inadequately vaccinated students and teacher at Western High get measles when they were children rather than as teenagers or adults?**

     Students should be able to explain that the unvaccinated or inadequately vaccinated students at Western High were protected by herd immunity when they were younger: Because most of the people around them were immune, the infectious agent could not be transmitted from those people.

   - **Why is vaccination not only a personal health issue, but also a public health issue?**

     Vaccination is a public health issue because maintaining high levels of immunity in a population prevents epidemics and protects the small percentage of susceptible people from the disease.

Collect and review students' paragraphs to assess their understanding of the major concept of the activity. Address common misunderstandings in the next class session and read two or three of the best paragraphs to the class.

DAY 2 (Optional)

1. **Open the activity by reminding students about two-day disease and the simulation that they completed. Then ask them what characteristics may vary between two-day disease and other diseases. Point out that differences in these characteristics affect the likelihood that an epidemic of a particular disease will occur and the percentage of the population that must be immune to that disease to achieve herd immunity.**

   Expect students to suggest that people who are sick may contact more than one person per day, may be sick (and infectious) for more than two days, may die from the disease, and may not get sick from just one contact. Students also may point out that the disease may require "intimate" rather than casual contact or it may not require person-to-person contact.

2. **Ask students to predict what the results of the simulation would be if they varied each of four characteristics of the disease: virulence (the likelihood of dying from the disease), duration of infection, rate of transmission (how contagious the disease is), and level of immunity in the population. Insist that students provide some rationale for their predictions. Write their predictions on the board or a blank transparency.**

   To help students think about this, you may wish to ask questions such as "Do you think there would have been an epidemic of two-day disease if people sometimes died from the disease? If so, do you think it would have been a more or less severe epidemic?"

   Virulence, duration of infection, rate of transmission, and level of immunity are the four parameters that the computer simulation will allow students to vary. Students may make predictions such as "The more virulent a disease is, the greater the likelihood of an epidemic," or "The higher the immunity level of a population, the less likely it is that an epidemic will occur."

3. **Tell students that they will use a computer simulation to investigate the likelihood of an epidemic when they vary one of the four characteristics they just discussed. Distribute one copy of Master 4.5, *Disease Transmission Simulation Record*, to each student and ask students to organize into their teams. Assign each team one of the four characteristics to investigate and direct students to circle this characteristic on the master.**

   Tell students that because a larger population size is used in the computer simulation, an epidemic is defined as an outbreak of disease in which 10 percent or more of the population is sick at one time.

4. **Explain briefly how to access and use the simulation, then direct students to use it to test their assigned characteristic. Explain that teams should test four different levels of their assigned characteristic and that they have 15 minutes to complete this work before reporting their findings to the class.**

   You may wish to explain the following features of the simulation:

   - Users can set each disease characteristic at a variety of levels (as indicated on the screen).
   - Users can have the simulation run automatically for 30 days or step through those days one by one, depending on the button they click.
   - To repeat a run or to change the settings and do another run, users must click the Reset button.
   - Once a run begins, users cannot change the settings unless they click the Reset button.

You may want to suggest that teams that are assigned the virulence characteristic select four levels from the low end of the available range (less than .1 or .2) to test. Because of the levels students will be using for duration of infection and rate of transmission, any disease that has moderate to high virulence rapidly dies out in a population. Students will have more interesting results if they use the lower levels for virulence.

A range from 0.001 to 0.1 encompasses estimated rates of transmission for many infectious diseases. The algorithm for this simulation assumes that each infected person makes 100 contacts per day. Thus, the range of settings available to students is 0.1 (0.001×100) to 10 (0.1×100). The simulation would have to be adjusted for populations that are more or less dense than the one assumed by the simulation.

Note to teachers: The simulation will allow students to enter values for the disease characteristics that are outside the indicated range. However, the results of those simulations may not be reasonable.

5. **Reconvene the class and ask questions such as "Did your predictions match what you discovered using the simulation?" or "Were you surprised by the results of the simulation?" Ask one of the teams that investigated the effect of varying virulence level to read its summary statement to the class. Invite other teams that investigated that characteristic to add more information to the statement or to disagree with it. Repeat this process for the other three characteristics the teams investigated.**

Students should have discovered the following, according to the computer simulation:

Virulence: A disease that is not very virulent remains at a low level in the population, whereas those that are quite virulent rapidly die out. Real disease examples that show this are colds and Ebola hemorrhagic fever. Colds are not very virulent, and infected individuals remain contagious for several days. Thus, colds tend to remain at a fairly constant low level in the population. Ebola fever is very virulent (50–90 percent mortality) and death occurs shortly after infection, lessening the opportunities for an infected individual to spread the virus beyond his or her immediate surroundings. Therefore, at least until recent improvements in travel in areas where Ebola has occurred, it tended to occur in isolated outbreaks that died out fairly quickly.

Duration of infection: As the duration of infection increases, infected individuals have more opportunities to transmit the infection to others. In turn, each secondarily infected individual has more opportunity to infect still others. Therefore, because larger numbers of people become infected within a short period of time, epidemics become apparent sooner after introduction of infected individuals into the population, reach a higher peak incidence, and last longer. Real disease examples showing this are influenza and chicken pox.

Rate of transmission: According to the computer simulation, a disease dies out at low levels of transmission, whereas it stabilizes and becomes endemic at high levels. Real disease examples of this include malaria and many diarrheal diseases. Public health measures and access to medical care result in dramatically decreased transmission of these diseases in the United States, but they remain endemic in developing countries where such public health measures and medical care are not readily available.

Level of immunity: With virulence, duration of infection, and rate of transmission set at the values for two-day disease, the computer simulation predicts that an epidemic will not occur when the proportion of immune people in the population is greater than 15 percent.

6. **Explain to students that computer simulations such as the one they have explored are useful tools for epidemiologists, who use them to make predictions about the likelihood of an epidemic occurring in a particular population or to estimate the level of vaccination coverage they must achieve to prevent epidemics in the population.**

7. **Challenge students to work in their teams to use the simulation to estimate the level of immunization required to prevent epidemics of three real diseases: smallpox, polio, and measles. Assign each team one of the diseases and display Master 4.5, *Characteristics of Smallpox, Polio, and Measles*, which provides the settings they need for the simulation. Tell teams they have 10 minutes to complete their work.**

   Smallpox was declared eradicated from the world in 1980. Because epidemiologists knew it would not be possible to vaccinate everyone in the world, they used mathematical models of the spread of disease to estimate the level of vaccination coverage they needed to achieve and maintain to establish herd immunity in a population. (The computer simulation in this activity is based on a similar mathematical model.) Epidemiologists knew smallpox would eventually be eliminated because there would not be enough susceptible people to transmit the smallpox virus. Polio and measles are among the next targets for global eradication.

8. **Poll teams for their results and add them to the appropriate column of *Characteristics of Smallpox, Polio, and Measles*. Explain that epidemiologists using more sophisticated simulations make similar predictions: 70 to 80 percent for smallpox; 82 to 87 percent for polio; and 90 to 95 percent for measles.**

   Based on the computer simulation, students should suggest the following percentages be vaccinated to avoid an epidemic: smallpox—no epidemic if 78 percent or more of the population is immune; polio—no epidemic if 86 percent or more of the population is immune; measles—no epidemic if 90 percent or more of the population is immune. The critical proportions of the population to be immunized for eradication, above, are reported by Anderson and May (1992). You may want to write those percentages beside the students' findings.

9. **Explain to students that the predictions made by models are sometimes inaccurate: A predicted epidemic may or may not occur in a real population. These comparisons between actual disease epidemics and epidemics predicted by models reveal the limitations of a model. For example, additional factors, not accounted for by a model, may have an impact on the spread of a disease.**

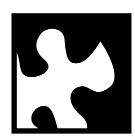
10. **As an example of the limitations of their model of the spread of a disease, display Master 4.6, *Cases of Smallpox in Niger and Bangladesh*. Tell students to make an observation about how accurate their prediction for smallpox was for each of the two countries.**

    Students should observe that, even though both countries had about the same level of vaccination coverage (79 percent for Niger and 80 percent for Bangladesh), outbreaks of smallpox apparently occurred in Bangladesh (.23 cases per square kilometer) but not in Niger (.00002 cases per square kilometer). The students' model predicted that, if 76 percent of the population is immune, such outbreaks would not occur.

11. **Ask students to suggest factors their model did not take into account that may explain discrepancies between their prediction and the actual result in Bangladesh. Then, add the following information to the transparency: In 1969, Niger had 310 people per square kilometer, while in 1973, Bangladesh had 50,000 people per square kilometer.**

    Students may note that crowded conditions will affect the spread of a disease because a sick person would be able to contact and transmit the disease to more people. This "population density" factor appears to be the explanation for the occurrence of outbreaks of smallpox in Bangladesh even though recommended levels of vaccination had been achieved. (The impact of different population densities are not accounted for in the computer simulation in this activity, which assumes the same population density for all populations.)

    Other factors not accounted for in the simulation that also may affect the likelihood of epidemics include the general health of the population, the nutritional status of the population, and the level of sanitation in the population. Point out that the immune system is stressed when it is combating a disease, so people who are already sick are more susceptible to additional diseases. Similarly, good nutrition is essential for a healthy immune system, so people who are malnourished are likely targets for pathogens. Unsanitary conditions provide greater opportunities for transmission of infectious agents. All of these factors will increase the proportion of the population that must be immune to achieve herd immunity.



This step gives students an opportunity to revisit the idea of herd immunity and to reflect on their expanded understanding of the concept.

12. **Ask students to think about the ways they used the computer simulation in this activity and what the results of their simulations revealed about**

the spread of diseases. Then, ask them to write down one thing they learned from the activity. Ask several students to share what they learned and clarify anything that students have misunderstood.

The major point of this activity is that the characteristics of diseases vary and these characteristics have an impact on the likelihood of epidemics. Similarly, these characteristics have an impact on the percentage of people in a population who must be vaccinated to achieve herd immunity.

Potential Extensions

The World Health Organization maintains a Web site that includes information on infectious diseases that are targeted for eradication. Ask students to review the site and report (1) the vaccination coverage goal for a particular disease, (2) the challenges that face health care workers for meeting that goal, and (3) the strategies epidemiologists are using to meet their goals.

The address for the site is www.who.org/aboutwho/en/disease-er.htm.

Simulating the Transmission of Two-Day Disease

The disease transmission simulation simulates the spread of two-day disease in a population. Explain to students that during the first simulation, all the students will be susceptible to two-day disease. When 25 percent or more of the class is sick, they are experiencing an epidemic.

Give each student one red card, one pink card, and one black card. Explain that on the first day they become sick, they will hold up a red card. On the second day of their illness, they will hold up a pink card, which signifies that they are recovering but still infectious. On the third day, they will hold up a black card to show that they have recovered and are immune. They will hold the black cards and remain immune until the simulation ends.

Tip from the field test. Have the students stack the cards with black on the bottom, pink in the middle, and red on top.

Simulation 1
0% immune, 100% susceptible

1. Write "Simulation 1—0% immune, 100% susceptible" at the top of one of the transparencies of Master 4.3, *Following an Epidemic*. Tell students to do the same on one of their copies of *Following an Epidemic*.
2. Identify one student sitting in the center of the class to be the individual who introduces the disease to the population. Tell that student to pick up his or her red card. This is **Day 1**. On the transparency, tally the number of currently sick people and the number currently immune. Tell students to record those results on their copies as well.
3. Tell the sick student to tap one person *he or she can reach from a seated posi tion*, then announce the end of **Day 1**.
4. Announce the beginning of **Day 2** and remind the original sick student that he or she is still sick, but recovering and should be holding the pink card. Remind the tagged student that he or she is now sick and should be holding the red card. Complete the **Day 2** row of the table, asking students to do the same.
5. Tell the sick students to tag other students *they can reach from their seated position*. Announce the end of **Day 2**.
6. Announce the beginning of **Day 3**. The original sick student should now put down the pink card and pick up the black card to indicate that he or she is immune. The student tagged first should put down the red card and pick up the pink card. The two newly tagged students should pick up their red cards. Complete the **Day 3** row of the table.
7. Tell the sick students to tag other students they can reach from a seated position. Announce the end of **Day 3**.

8. Repeat Steps 6 and 7 until all students have had the illness or until transmission of the disease stops because there are no susceptible students near sick students.
9. Ask students to raise their hands if they were sick at some point during the simulation. Count the number of hands and record this number at the bottom of the transparency.
10. Plot the data from the table onto the graph and draw the curve on the graph. Tell students to do the same and then ask them to make three or four observations about the table and graph the class has created.

Simulation 2
50% immune; 50% susceptible

1. Write “Simulation 2—50% immune, 50% susceptible” at the top of the other transparency of *Following an Epidemic.* Tell students to do the same on their other copy.
2. Tell students to restack their cards, with black on the bottom, pink in the middle, and red on top.
3. Explain that they will complete the simulation again, but this time half of the students in the class will be immune to the disease. Note that, as is often the case in real life, students will not know who is immune and who is susceptible. Give half the students a folded card that says “immune” and half a folded card that says “susceptible.” **They should read their card, but they should not share this information with anyone.**
4. Explain that if they received a card that says “immune,” they are not to pick up their black cards until they are tapped by a sick student. Write the number of immune cards you distributed in the “Day 1/Number of People Immune” cell on the transparency and tell students to do the same on their copy of the table. This is the initial number of immune people.
5. Identify one student sitting in the center of the class to be the individual who introduces the disease to the population. Tell that student to pick up his or her red card. This is **Day 1**. On the transparency, tally the number of currently sick people and the number currently immune. (For the latter, add the number of people who are newly immune to the number who were already immune.) Do **not** ask students to indicate by a show of hands how many people are immune, because this will reveal who is immune and who is susceptible and may influence the choices students make as they transmit the disease. Tell students to record the number sick and the number immune on their copies as well.
6. Continue the simulation as before, but this time, when an immune student is tapped, he or she should immediately hold up the card that says immune. He or she is not infectious and so will not tap another student. (Do **not** add this person to the number who are currently immune, because he or she was already included in the initial count of immune individuals.)

7. Continue until either all students are immune or have had the illness, or until transmission of the disease stops because there are no susceptible students near sick students.
8. Ask students to raise their hands if they were sick at some point during the simulation. Count the number of hands and record this number at the bottom of the transparency.
9. Plot the data from the table onto the graph and draw the curve on the graph. Tell students to do the same and then ask them to make three or four observations about the table and graph the class has created.